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XI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXXIII. — THE STRENGTH OF THE INDUCED CURRENT WITH A MAGNETO TELEPHONE TRANSMITTER AS INFLUENCED BY THE STRENGTH OF THE MAGNET.

By Charles R. Cross and Arthur S. Williams.

Presented November 14, 1888.

It is a well-known fact in practice, as well as an evident consequence of theoretical considerations, that the effectiveness of a magneto telephone when used either as a transmitter or as a receiver varies with the strength of the magnetism of the core. But the relation of the one to the other has never been studied, so far as we are aware.

Our investigations include a study of the changes in strength of the current produced by a magneto transmitter under varying conditions of magnetization, and of the magnitude of the momentary changes in the magnetic condition of the core of the receiving telephone when subjected to the action of undulatory or other brief currents, as influenced by the strength of the primitive permanent magnetization of the core. The present paper contains only the results of a series of experiments relating to the first of these, that is, to the effect of varying strength in the magnet of the transmitter, the study of the allied problem of the receiver being still in progress.

The apparatus employed consisted of a cylindrical bar of soft iron about $4\frac{1}{2}$ inches in length and $\frac{1}{4}$ of an inch in diameter, around one end of which was placed a coil of fine wire similar to that used in ordinary telephonic practice. The resistance of this coil was 100 ohms. It was placed in circuit with a ballistic mirror galvanometer, from whose deflection the momentary current produced in the coil by any variation in the strength of the core could be determined. The diaphragm, which was in all cases $2\frac{5}{16}$ inches in diameter, was in its usual place opposite the end of the magnet about which the wire coil was wound, and about $\frac{3}{100}$ of an inch from that end. By means of a rod carrying a cam moved by a weight, a rapid inward push of definite amount was given to the diaphragm, thereby inducing a current in the coil already referred to, and so deflecting the needle of the ballistic galvanometer. The soft iron bar was also surrounded by a second helix, through which was passed a current from a storage battery, serving to magnetize the core. A tangent galvanometer inserted in this circuit gave the strength of the magnetizing current. A magnetometer placed in the prolongation of the axis of the core, which last occupied an east and west position, made known the relative strengths of the field produced by the core under different conditions of magnetization.

Corresponding observations of the magnetometer reading, and of the current induced when the diaphragm was moved by the cam, were made throughout a widely varying range of strength of field, and the results were represented graphically by constructing a series of curves in which ordinates represent the relative strength of field, and abscissas the current due to a given predetermined throw of the diaphragm (about $\frac{1}{100}$ of an inch), as ascertained from the readings of the ballistic galvanometer.

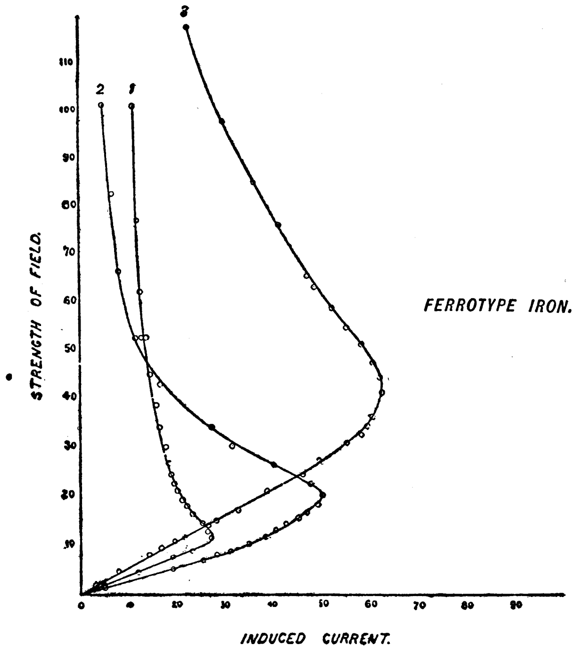

Fig. 1.

One of these curves is shown at 1, Figure 1, the core in this case being a cylindrical bar of Norway iron $4\frac{1}{2}$ inches long and $\frac{1}{4}$ of an inch in diameter, and the diaphragm an ordinary disk of ferrotype iron $2\frac{5}{16}$ inches in diameter and $\frac{1}{100}$ of an inch thick (No. 31 B. W. G.).

Table I. gives the data from which Figure 1 was constructed. The strength of field is given in terms of the tangents of the angles of deflection of the magnetometer needle. The induced current is given in arbitrary units, as only relative values are needed. A determination of the value of the deflections was made by observing the excursion due to the discharge of a condenser through the ballistic galvanometer, and it was found that the abscissa 100 on the curves corresponds to a sudden discharge of approximately 0.00000097 of a coulomb through the coils of the galvanometer.

TABLE I.

CORE, NORWAY IRON. — DIAPHRAGM, DISK OF FERROTYPE IRON, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
. . .	0.7	.211	20.5
.016	3.3	.229	19.8
.044	12.0	.248	19.2
.058	19.3	.270	18.7
.089	23.3	.302	18.0
.118	27.0	.342	16.9
.141	26.8	.390	16.1
.132	26.6	.454	14.7
.146	25.3	.530	13.3
.164	23.8	.625	12.7
.182	22.5	.773	12.0
.196	21.6	1.014	11.5

Cores of Bessemer steel and of untempered soft steel were also used, with results given in Tables II. and III.

TABLE II.

CORE, BESSEMER STEEL. — DIAPHRAGM, DISK OF FERROTYPE IRON, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.005	2.0	.279	17.8
.030	7.7	.333	16.7
.082	20.7	.396	15.0
.137	26.7	.507	13.5
.160	24.8	.625	11.7
.191	21.2	.748	10.8
.213	19.3	.907	9.7
.248	18.6	1.099	8.7

TABLE III.

CORE, UNTEMPERED SOFT STEEL. — DIAPHRAGM, DISK OF FERROTYPE IRON, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.031	8.2	.275	18.0
.049	12.0	.321	16.5
.089	22.0	.388	15.2
.137	25.9	.473	13.8
.157	24.9	.618	12.7
.171	22.9	.776	11.0
.194	21.1	1.011	9.5
.216	19.7		

An examination of Figure 1, as well as of the various curves following it, will show that the effect of increasing the strength of the magnet of the transmitter is in all cases to cause at first a rather rapid increase of the strength of the induced current, which later increases less rapidly, rising soon to a maximum value, from which it falls off, at first rapidly, and afterwards more and more slowly as the strength of the field is further increased. We proceed to consider the explanation of these results.

It is evident that three distinct sources of variation exist to affect the current furnished by a magneto transmitter as the strength of the magnet is increased. First, the direct effect of the increased strength of field in which the diaphragm moves is to increase proportionally the strength of the induced current, since it increases correspondingly the rate of change in the number of lines of force enclosed by the coil of the instrument; second, an approach toward saturation of the magnet, so far as it alone is concerned, will tend to diminish the induced current, on account of the smaller variation in the strength of the pole due to a given motion of the diaphragm; and, third, the nearer approach toward saturation of the diaphragm will have the same tendency.

The rapid rise in the induced current at the beginning is of course due to the predominating influence of the increasing strength of the field in which the diaphragm moves, as both core and diaphragm are then but slightly magnetized. The subsequent changes in the current must be explained by a consideration of the increasing magnetization of either the core or the diaphragm, or both.

It will be seen by comparing Tables I., II., and III., that the value of the maximum induced current for a given excursion of the diaphragm is approximately the same with all the three cores used, and that the same is true as to the strength of field corresponding to this maximum current. Moreover, saturation curves constructed for the several cores showed that in all cases the magnet was still very far removed even from half-saturation when the maximum induced current was obtained. From these facts it appears that the degree of saturation of the magnet is practically unimportant, so far as the general results shown in Figure 1 are concerned.

It remains to observe the part played by the increasing magnetization of the diaphragm. Other things remaining the same, as this approaches more and more closely towards saturation the increase in the number of lines of force passing between it and the magnet on the approach of the diaphragm to the magnet must become smaller and smaller, and this change will tend to oppose the effect of the increased absolute strength of the magnetizing force. The small mass of the diaphragm will evidently cause it to show the effect of an approach to saturation while the core is far below that condition. And such an action will clearly explain the observed changes in the current strength.

In order to test this matter still further, the experiment was tried of varying the mass and material of the diaphragm.

The results are shown by the curves in Figures 1, 2, and 3, which are constructed from the data given in Tables I. to X.; further results of the same character are given in Tables XI. and XII.

TABLE IV.

Core, Norway Iron. — Diaphragm, Two superposed Disks of Ferrotype Iron, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.016	5.0	.184	49.3
.054	19.3	.205	50.2
.070	25.7	.229	48.0
.081	28.5	.266	40.3
.089	30.2	.306	31.8
.103	35.0	.342	27.7
.119	38.5	.433	16.7
.133	40.7	.530	11.9
.144	42.7	.667	8.3
.155	45.7	.830	7.0
.169	47.0	1.018	5.0

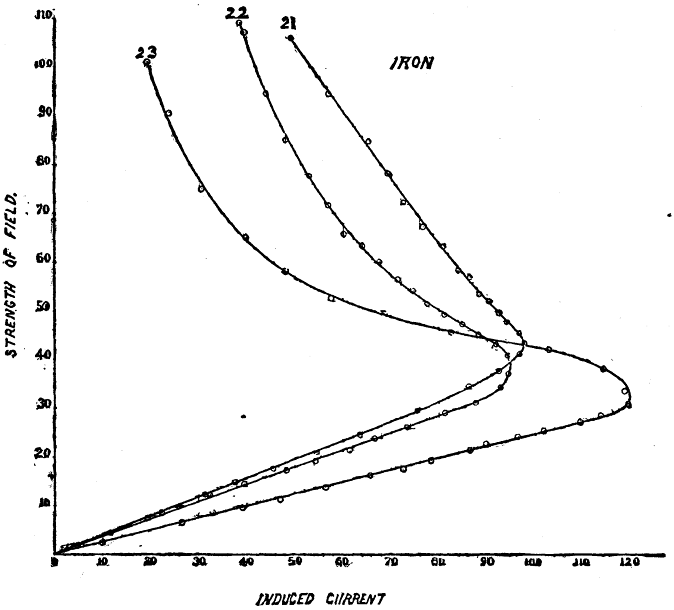
IRON
21
22
23
STRENGTH OF FIELD.
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
120
INDUCED CURRENT

Fig. 2.

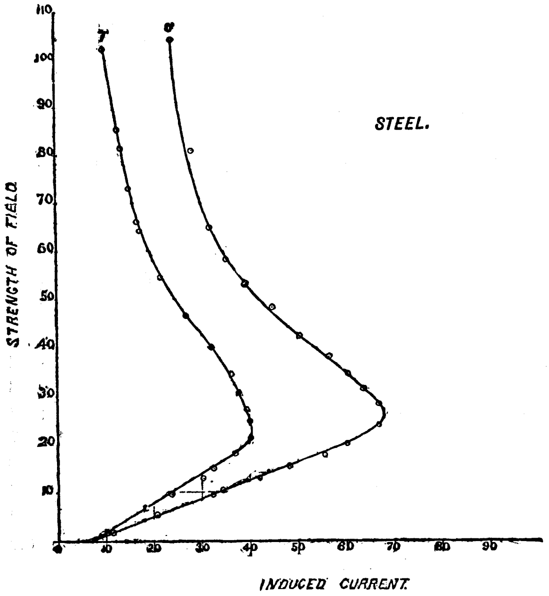
STEEL.
7
8
STRENGTH OF FIELD
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
INDUCED CURRENT.

Fig. 3.

TABLE V.

Core, Norway Iron.—Diaphragm, Three superposed Disks of Ferrotype Iron, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.5	.346	59.7
.018	3.2	.366	60.7
.047	8.0	.390	61.3
.079	14.2	.416	63.0
.084	14.7	.445	62.3
.096	17.0	.479	61.0
.110	19.7	.514	58.5
.118	21.8	.550	55.7
.135	25.5	.591	52.4
.151	28.3	.637	48.7
.175	33.0	.659	47.3
.213	39.0	.765	41.7
.249	46.3	.854	36.7
.277	49.8	.983	30.0
.313	55.3	1.180	22.8
.329	58.7		

TABLE VI.

Core, Norway Iron.—Diaphragm, Sheet Iron, No. 21.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
. . .	0.3	.456	96.7
.016	3.1	.477	94.0
.058	13.7	.499	92.5
.082	20.3	.521	90.5
.102	25.2	.536	88.3
.125	31.2	.573	86.7
.150	37.8	.584	84.0
.178	45.5	.637	81.0
.213	54.7	.675	76.7
.249	63.8	.724	72.3
.296	75.5	.784	69.3
.348	86.2	.851	65.6
.378	92.3	.949	57.3
.416	96.7	1.061	49.1
.437	97.8		

TABLE VII.

Core, Norway Iron. — Diaphragm, Sheet Iron, No. 22.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
...	1.7	.410	94 2
.018	4.7	.431	92.0
.047	11.7	.452	88.3
.075	19.7	.473	85.0
.088	22.3	.494	81.2
.100	26.0	.516	77.5
.123	32.5	.541	74.7
.146	39.5	.566	71.3
.171	48.2	.601	67.7
.194	54.2	.635	64.0
.218	61.3	.659	60.0
.240	66.9	.719	56.7
.262	73.2	.779	53.0
.292	81.3	.851	48.0
.313	87.7	.946	44.0
.342	92.7	1.072	39.3
.372	94.3	1.091	38.3

TABLE VIII.

Core, Norway Iron. — Diaphragm, Sheet Iron, No. 23.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
...	1.7	.272	109.3
.026	10.0	.289	113.8
.068	26.8	.310	119.3
.086	33.0	.339	118.6
.096	39.0	.382	114.1
.116	47.0	.420	102.9
.139	56.3	.458	82.2
.162	65.8	.499	68.7
.176	72.3	.529	57.6
.194	78.3	.582	48.0
.216	86.4	.652	39.9
.229	90.0	.751	30.8
.242	96.3	904	23.7
.255	101.8	1.011	19.0

TABLE IX.

Core, Norway Iron. — Diaphragm, Steel, No. 26, Untempered.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.004	7.7	.281	66.7
.019	11.5	.313	63.8
.054	20.5	.342	60.4
.095	32.2	.380	56.3
.105	34.5	.422	50.5
.128	42.0	.483	44.7
.153	48.3	.530	39.0
.178	55.7	.584	35.3
.200	60.3	.652	32.0
.227	64.3	.810	28.2
.236	67.0	1.043	24.3

TABLE X.

Core, Norway Iron. — Diaphragm, Steel, No. 26, Tempered.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.002	7.8	.344	36.3
.019	10.4	.400	32.0
.068	18.5	.466	26.9
.096	23.8	.545	21.7
.128	30.3	.642	17.7
.151	32.4	.662	17.3
.180	37.0	.732	15.2
.214	40.2	.816	13.8
.246	40.0	.854	13.0
.272	39.5	1.025	10.0
.304	37.9		

TABLE XI.

Core, Norway Iron. — Diaphragm, Steel, No. 22, Untempered.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.007	6.2	.272	36.7
.023	8.0	.302	34.8
.070	17.3	.340	33.0
.103	23.0	.392	29.7
.121	26.4	.458	26.3
.139	30.1	.538	23.2
.157	32.8	.566	23.0
.176	35.0	.647	21.7
.202	37.1	.773	19.8
.224	34.9	1.046	17.6
.246	37.0		

TABLE XII.

CORE, NORWAY IRON. — DIAPHRAGM STEEL, NO. 30, TEMPERED.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.007	6.2	.272	36.7
.023	8.0	.302	34.8
.070	17.3	.340	33.0
.103	23.0	.392	29.7
.121	26.4	.458	26.3
.139	30.1	.538	23.2
.157	32.8	.566	23.0
.176	35.0	.647	21.7
.202	37.1	.773	19.8
.224	...	1.046	17.6
.246	37.0		

TABLE XIII.

CORE, NORWAY IRON. — DIAPHRAGM, STEEL, NO. 30, UNTEMPERED.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.005	5.2	.331	31.2
.031	11.7	.376	28.9
.082	24.2	.437	26.0
.103	29.7	.512	23.3
.130	37.7	.632	20.4
.160	41.9	.735	19.7
.200	38.3	.819	18.0
.231	36.2	.956	16.3
.272	35.2		

Curve 2, Figure 1, represents the results when two of the ordinary ferrotype diaphragms were superposed, forming a diaphragm of double thickness, and Curve 3 of the same figure shows the results when three such diaphragms were superposed. Each diaphragm was 0.01 of an inch thick. The curves of Figure 2, marked 21, 22, 23, respectively, show the results of similar experiments with diaphragms of sheet iron whose thickness was 0.030, 0.027, 0.024 of an inch, respectively (Nos. 21, 22, 23, B. W. G.). Figure 3 shows the results when a steel diaphragm 0.017 of an inch thick (No. 26) was used, the curve *U* being that for untempered steel, and *T* that for tempered steel. Steel diaphragms respectively 0.026 and 0.012 of an inch thick (Nos. 22 and 30) gave similar results, as will be seen from Tables XI., XII., and XIII.

An inspection of these curves shows immediately that the greater the strength of the field required to saturate the diaphragm, the greater is the strength of the field at which the maximum current occurs. Thus in Figure 1 the maximum current with Curve 1 corresponds to a strength of field of about 12 units of the scale used, while with Curves 2 and 3 the corresponding strengths of field are 20 and 43 units respectively. Also in Figure 2 the maximum currents will be seen to correspond to greater strengths of field in proportion to the thickness of the diaphragm, and in Figure 3 similar though less marked results hold for tempered as compared with untempered steel of the same thickness.

It would also be expected that the value of the maximum current would be greater with a thick than with a thin diaphragm. This was usually the case in our experiments. Thus the Curves 1, 2, 3, of Figure 1 give maximum currents of 27.5, 50.2, and 62.6 units respectively. Results of a similar nature are shown by Figure 3, the maximum current with the untempered diaphragm being far greater than with the tempered one. Curve No. 23 of Figure 2 is apparently an exception. It is probable, however, that this is in appearance only, and that the three curves of that figure are not strictly comparable with one another. The rigidity of the diaphragms here used, especially of the thicker ones, is considerable, and any slight yielding of the supports of the rod which carried the cam would prevent the actual throw of the diaphragm from being as great when this had considerable thickness, and would greatly diminish the strength of the current produced.

The peculiarity of Curve 2, as compared with 1 and 3, is probably caused by the want of both magnetic and mechanical continuity in the material of the multiple plate formed by the several diaphragms used.

In those cases where steel diaphragms were employed, there was always a notable induced current, even when the reading of the magnetometer was zero. This was probably due to a slight residual magnetization of the diaphragms.

The results stated in this paper may serve to explain a phenomenon which has seemed somewhat obscure. Frequent attempts have been made to increase the efficiency of a magneto transmitter by polarizing the diaphragm as well as the magnet, a common way of doing this being to employ a horseshoe magnet one leg of which is in contact with the edge of the diaphragm, while the other, about which the coil is wound, is placed in its usual position opposite the centre. But as a general rule little or no gain has seemed to result therefrom, so far as can be judged by the performance of such instruments in actual practice. It is quite probable in this case that the increased approach to saturation of the diaphragm may have so great an effect as entirely to prevent the expected improvement.

It will also be seen from our results, that an increase in the thickness of the diaphragm of a magneto transmitter tends to allow of the use of a stronger magnet, and for a given amplitude of vibration to produce a stronger current. But it must be remembered, on the other hand, that the greater rigidity of the thick diaphragm will diminish this range of vibration under the action of the voice, a difficulty which may to a certain extent be remedied by using a diaphragm of large diameter.

Rogers Laboratory of Physics,
October, 1888.